Casuarina equisetifolia L. ex J.R. & G. Forst.

Casuarina, Australian pine

SO-ITF-SM-56
February 1993

Casuarinaceae **Casuarina family**

John A. Parrotta

Casuarina equisetifolia L. ex J.R. & G. Forst., commonly known as casuarina, Australian pine, sheoak, and pino australiano, is a fast-growing, medium-sized evergreen tree that grows up to 45 m in height. This tree is distinguished by its rough, furrowed, light gray-brown bark and a thin crown of dark-green, drooping, photosynthetic twigs or branchlets (fig. 1). Native to coastal areas of tropical Australia and Southeast Asia (fig. 2), casuarina has been introduced and naturalized throughout the Caribbean and elsewhere in the Tropics and subtropics. It is a useful species for reforestation of coastal areas and degraded lands and is valued as a source of fuel, posts, and tannins. Two subspecies, *incana* and *equisetifolia*, are recognized. The former is a small tree native only to Australia; the latter is a much larger tree and is more widely distributed. All the information contained in this monograph pertains to the subspecies *equisetifolia*.

HABITAT

Native and Introduced Ranges

Casuarina is native to the Andaman Islands (India) and seacoasts from southern Bangladesh, Myanmar (formerly Burma), Thailand, and Malaysia to subtropical Australia, Melanesia, Micronesia, the Philippines, and Polynesia between latitudes 22° N. and 32° S. *(5)* (fig. 2). It has been introduced and became naturalized in southern India, Hawaii, southern Florida, the Caribbean, coastal regions of Mexico and Central America, and South America *(57, 112)*. In the Caribbean, casuarina was introduced to Cuba by the early 19th century *(8)*.

Extensive plantations have been established in China, Thailand, India, Kenya, Portugal, and the island of Corsica and also in the Middle East, north Africa, west Africa, and south Africa *(76)*. In Puerto Rico, hundreds of thousands of casuarina have been planted since 1924 on Commonwealth and National Forest lands, along coasts and roadsides, and on private lands *(67, 68)*.[1]

Climate

Casuarina grows best in humid tropical and subtropical climatic zones. Within its native range annual rainfall ranges from 700 to 5000 mm, and often there is a dry season of 6 to 8 months. In Australia, casuarina occurs primarily in the hot humid zone, with some extension into the hot and warm subhumid climatic zones. Frosts are absent in all of the coastal strand, although in the extreme southern portion of its range there may be one to three frosts per year within a few kilometers of the sea. Annual rainfall through most of casuarina's Australian range is between 1000 and 1500 mm, with seasonal distribution varying from a strong summer maximum in the south to a strong monsoonal pat-

Figure 1. — *Casuarina* (Casuarina equisetifolia) *in Puerto Rico.*

[1]Unpublished data on file at: International Institute of Tropical Forestry, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Río Piedras, PR 00928-2500.

John A. Parrotta is a research forester at the International Institute of Tropical Forestry, U.S. Department of Agriculture, Forest Service, Río Piedras, PR 00928-2500, in cooperation with the University of Puerto Rico, Río Piedras, PR 00928-2500.

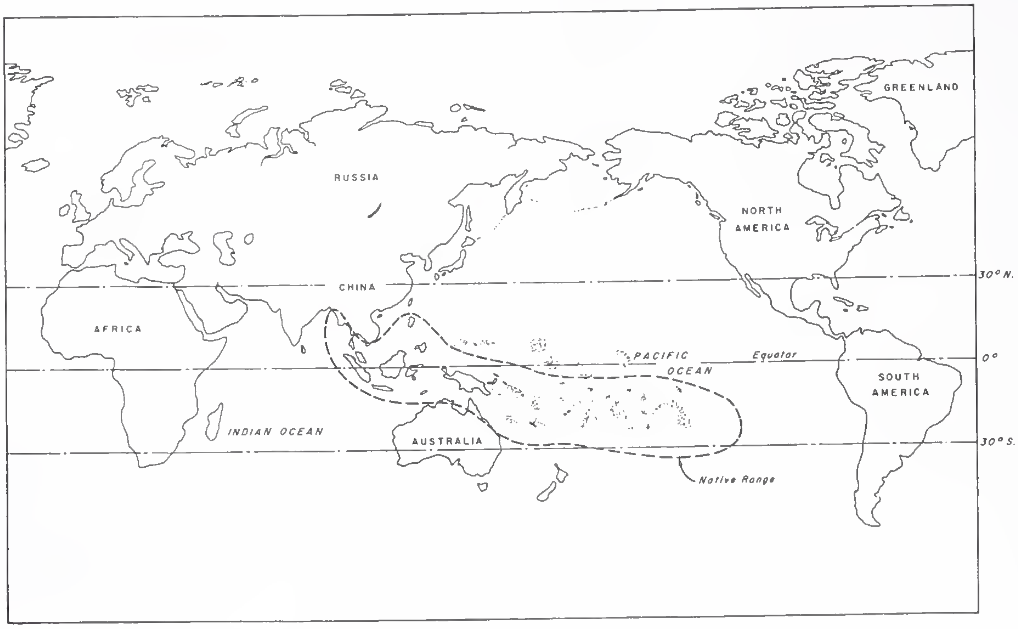

Figure 2.—*Native range of casuarina* (Casuarina equisetifolia).

tern in the north *(25)*. On the coasts of Myanmar and the Andaman Islands (India), annual rainfall ranges from 2500 to 5000 mm, with mean minimum and maximum shade temperatures ranging from 7 to 16 °C and 37 to 38 °C, respectively *(100)*.

Casuarina has been planted successfully in areas having an annual rainfall of 200 to 6000 mm *(76, 84)*, although the best growth occurs on sites receiving 700 to 2500 mm of annual rainfall *(107)*. In its introduced range, casuarina grows well where mean annual temperatures range from 18 to 28 °C, with mean temperatures of 20 to 35 °C during the hottest month and 10 to 20 °C during the coldest month *(13, 107)*. Light frosts are reported to cause only minor damage to well-established trees *(71, 88, 100)*, although temperatures of approximately –8 °C can kill trees less than 0.5 m in height *(88)*.

In Puerto Rico, casuarina plantations have been established in the subtropical dry, subtropical moist, and subtropical wet forest life zones *(30)*. Mean annual rainfall in these areas ranges from 600 to 4000 mm, with most sites receiving between 1250 and 2000 mm *(31)*.

In southern China, where extensive shelterbelt plantations have been established along the coasts of the Guangdong and Fujian provinces and the Guanxi autonomous region, mean annual rainfall ranges from 1400 to 1600 mm, and there is a 6-month dry season. Mean annual temperature in this region is 24 °C, with an absolute maximum of 37 °C *(101)*.

In southern India, casuarina grows well in areas having a well-distributed rainfall ranging from 850 to 3800 mm/yr *(100)*. In coastal areas, the mean minimum and maximum temperatures range from 7.5 to 17.5 °C and 37.5 to 47.5 °C, respectively. In inland areas casuarina is grown under conditions of greater temperature extremes *(100, 112)*.

Soils and Topography

In its native range, casuarina occurs in coastal regions on dunes, sandy flats, and gently sloping topography up to 100 m in elevation. Soils are typically sands overlying sandy loams *(25)*. In Micronesia, casuarina occurs naturally along coasts and in upland savannas on both limestone and volcanic soils *(76)*. Where introduced, casuarina grows from near sea level to altitudes of 1,750 m *(13)*.

Casuarina grows best on porous, well-drained soils with adequate moisture and nutrient supplies, such as river alluvium or sandy loam. Good growth occurs on nutrient-poor sands as well as on calcareous and moderately saline soils *(4, 17, 27, 66, 74, 111)*, although growth rates decline under conditions of excessive salinity and sodium saturation *(54, 113)*. Casuarina grows well in soils having a wide range of pH, from 5.0 to 9.5 *(13, 76, 113)*. This tree has been successfully grown on difficult sites such as dune sands *(64)*, limestone and tin-mine spoils *(29, 96)*, and sterile pumice *(76)*. Phosphorus deficiencies, evidenced by purplish discoloration of branchlets, inhibit nitrogen fixation by *Frankia* symbionts and may limit productivity of casuarina on some sites *(2)*. Potassium deficiencies are believed to contribute to widespread mortality in some Indian plantations *(77)*.

In Puerto Rico, casuarina has been planted along coasts, on coastal plains, and in foothills up to about 500 m in elevation. Good growth occurs on well-drained coastal sands, sandy loams, silty clay loams, and clays within the soil orders Entisols, Inceptisols, Mollisols, Oxisols, and Vertisols *(35, 61, 67, 68)*.[1] Plantation failures are common on Ultisols on cool, wet sites above 500 m in elevation.[1] Growth is generally better on the coastal plains and in large river valleys than on sites at higher elevations *(67)*. On upland sites, better growth has been reported in valleys on slopes.[1]

The depth below the surface on the soil and fluctuation of the water table greatly influence the growth of casuarina. On favorable sites such as coastal beaches or dunes, the water table is usually located at depths of 1.5 to 4 m below the soil surface, and there is little seasonal fluctuation *(113)*. Prolonged drought causing significant lowering of the water table to depths below 4 or 5 m, the presence of root-impermeable horizons above the water table, and extended periods of waterlogging are all deleterious to growth of casuarina *(104, 112)*.

Associated Forest Cover

In the coastal strand where casuarina mainly grows in its native range, the species typically forms pure stands in association with a ground cover of grasses and herbs *(25, 40, 100)*. In Myanmar, casuarina grows in nearly pure stands along the coast with scattered individuals of *Pongamia glabra* Vent., *Calophyllum inophyllum* L., *Eugenia* spp., *Erythrina indica* Lam., *Thespesia populnea* (L.) Soland ex Correa, and *Hibiscus tiliaceus* L. as understory associates *(14)*. In Malaysia, it forms pure stands, sometimes with herbaceous understory associates *(12, 109)*. In Australia, casuarina also grows in narrow belts adjacent to mangrove forests or is scattered in open woodlands in association with *Eucalyptus* species *(25)*. In south Florida, casuarina usually forms pure stands *(20)*, although it sometimes grows in association with *Piscidia carthagenensis* Jacq., *Conocarpus erectus* L., *Rapanea guianensis* Aubl., *Eugenia* spp., *Randia* spp., *Chrysobalanus icaco* L., *Myrica cerifera* L., *Persea littoralis* Small, and *Metropium toxiferum* (L.) Krug & Urban *(19)*.

In dense stands, understory vegetation is usually very sparse because of a combination of the production of a thick, slowly decomposed litter layer and the high, potentially toxic concentrations of selenium and salts (on coastal sites) that often characterize the litter of casuarina *(76)*. Abundant natural regeneration of *Cordia alliodora* (R. & P.) Oken, *Inga vera* Willd., *Petitia dominguensis* Jacq., *Swietenia mahoganii* (L.) Jacq., and *S. macrophylla* G. King was observed in 4-year-old plantations at St. Just in Puerto Rico.[1] In Lajas, Puerto Rico, natural regeneration of *Chrysophyllum cainito* L., *Cupania americana* L., *Roystonea borinquena* O.F. Cook, *Albizia procera* (Roxb.) Benth., and *Leucaena leucocephala* (Lam.) de Wit has been observed in 12-year-old plantations (author, personal observation). In more open stands on coastal sites in Puerto Rico, understory associates include *Bucida buceras* L., *Tabebuia heterophylla* (DC.) Britton, *Andira inermis* (W. Wright) DC., and *Calophyllum brasiliense* Jacq.[1] In young casuarina plantations in India, natural regeneration of *Azadirachta indica* (L.) Juss. and *Santalum album* L. has been reported *(9)*.

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting.—Flowering in casuarina usually begins at 2 to 5 years of age. In Puerto Rico, flowering and fruiting are irregular and occur throughout the year *(58)*. In regions with more pronounced wet and dry seasons, flowering and fruiting are more regular and occur once or twice a year *(100, 102)*. Casuarina is usually monoecious, with male and female flowers separate but borne on the same plant *(57, 98)*, although in some regions, such as India, the species is predominantly dioecious *(50)*. Male flower clusters (spikes or catkins), which grow at the end of branchlets, are narrowly cylindrical, 1 to 2 cm long, and less than 3 mm wide. The tiny male flowers are crowded in rings among grayish scales, each flower consisting of one exposed brown stamen less than 3 mm long and two tiny brown sepal scales at the base. Female flower clusters are short-stalked globular or ovoid spikes less than 3 mm in diameter. Individual female flowers consist of a pistil 5 mm long, including an ovary, a very short style, and two long, threadlike, dark-red stigmas *(57)*. Casuarina is wind-pollinated.

The multiple fruit is a hard, woody, conelike ball 13 to 20 mm in diameter that is often longer than it is wide. Each of these "cones" consists of 70 to 90 pointed fruits; each fruit is 3 mm long and 3 mm wide *(57)*. When fully ripe, the cones range in color from gray green to reddish brown *(50)*.

Seed Production and Dissemination.—Upon maturity, the two bracteoles that form the individual fruits separate, which releases a single light-brown seed about 6 mm in length *(50, 57)*. The winged seeds are dispersed by wind.

The ripe cones can be collected by stripping them from clipped branches. Seeds reach maximum weight and germinability 18 weeks after anthesis, or when cones change in color from green to brown *(82)*. An evaluation of cones collected from trees ranging in age from 2 to 7 years indicated that the highest germination and seedling vigor resulted from seeds collected from 5-year-old trees *(82)*. Cones placed in trays, covered by a thin cloth, and dried under full sunlight will soon begin to release their seeds, usually within 3 days *(50)*. A kilogram of green cones (about 250 cones) yields between 20 and 60 g of seeds. There are 650 to 760 seeds per gram *(50, 102)*. The application of an insect repellant effective against ant predation is advisable during the drying process *(50)*.

Seedling Development.—Germination, which is epigenous, takes place 4 to 22 days after sowing and is optimized at 30 °C under well-lighted conditions *(8, 39)*. Casuarina seeds are usually sown without pretreatment, although soaking seeds for 36 hours in a 1.5-percent solution of potassium nitrate reportedly enhances germination *(82)*. In the nursery, seeds are generally germinated in trays under full sunlight at an optimal density of 1,000 to 7,500 seeds (2 to 10 g) per square meter *(13, 83)*. Nursery soils should be light textured, optimally sandy loams or a mixture of sand and peat moss *(42)*. Germination ranges from 40 to 90 percent for fresh seeds and from 5 to 25 percent for seeds stored in airtight containers at 4 °C for 1 year *(8, 13, 24, 50, 107)*.

Seeds do not retain viability for more than 3 months at ambient temperatures *(50, 100)*. Seeds stored at subfreezing (–7 °C) or close to freezing (3 °C) temperatures, with moisture contents of the seeds ranging from 6 to 16 percent, retain viability for up to 2 years *(102)*. In the Philippines, germination of seeds collected from different trees within a single plantation was highly variable, ranging from 33 to 75 percent for fresh seeds *(41)*. A significant positive relation-

ship between cone size and seed germination was also noted in this study.

Seedlings are transferred from germination trays to containers when they reach a height of 10 to 15 cm, usually within 6 to 10 weeks after germination. Seedling containers measuring approximately 15 cm in diameter and 20 cm in depth are recommended *(83)*. Seedlings may also be transplanted to new beds at densities of 100 to 400 seedlings per square meter to obtain bare-rooted planting stock *(24, 87)*. In tests conducted in Puerto Rico, bare-rooted stock planted in rows 15 cm apart with a distance of 2.5 cm between seedlings within rows yielded seedlings with thicker and more fibrous root systems than seedlings produced from seeds.[1] Seedlings should be kept under partial shade until shortly before outplanting. Seedlings reach plantable size (20 to 50 cm in height) in 4 to 8 months.

It is recommended that seedlings be inoculated in the nursery using pure cultures of effective *Frankia* strains or using an inoculum from a nodule suspension prepared from fresh, healthy nodules collected in the field. Inoculation can be made by dipping roots into the suspension or by direct application of the suspension to the soil *(98)*. Alternatively, crushed, fresh nodules, leaf litter, or soils from the vicinity of effectively inoculated trees may be incorporated directly into the nursery potting mix *(99)*.

Natural regeneration of casuarina from seeds is poor in closed stands, but seedlings are readily established in open, disturbed sites *(98)*. Although casuarina's rapid natural regeneration is advantageous for revegetation of sand dunes, mining sites, and other derelict lands, it has been a problem in some areas, such as southern Florida, where it has colonized disturbed native vegetation formations *(18, 75)* and interfered with the nesting of sea turtles on foreshore dunes *(34)*.

Plantations may be established using containerized seedlings, bare-rooted plants, transplants, or rooted cuttings. Seedlings are very sensitive to both drought and excessive moisture *(100)*.

Vegetative Reproduction.—Casuarina has a strong tendency to spread horizontally through rooting of branches when trees are damaged or deformed by high winds, as commonly occurs on sand dunes *(50)*. Casuarina coppices only to a limited extent and usually only in trees up to 4 years of age *(116)*, although good coppice production has been reported in older plantations *(76, 100)*. Root suckering is commonly observed when stems are damaged, particularly in coastal plantations *(76, 100)*. Casuarina is easily propagated by rooting of stem cuttings *(62)*, lateral or side shoots, terminal branchlets, heel cuttings, or basal sprouts *(93, 98, 119)*. Tissue culture plantlets have been produced using explants from the epicotyl and root of seedlings and explants from immature female inflorescence *(26)*.

Sapling and Pole Stage to Maturity

Growth and Yield.—Casuarina is a fast-growing, though short-lived, tree that rarely survives beyond 50 years. Mature trees usually attain maximum heights of 25 to 40 m, with diameters at breast height (d.b.h.'s) of 40 to 50 cm. On favorable sites, growth is rapid during the first 5 to 8 years. Data on tree growth for plantations established in Puerto Rico are presented in table 1. The largest individual

Table 1.– *Mean d.b.h., height, and basal area of casuarina* (Casuarina equisetifolia) *plantations in Puerto Rico*

Location	Age	D.b.h.	Height	Basal area	Reference
	Years	*cm*	*m*	*m^2/ha*	
Aguirre	28	33.5	15–17	....	*
Añasco	13	15–20	18–24	....	*
El Verde	3	6.1	11.0	....	*
	14	13–33	11–18	....	*
	18	25.4	....	....	*
	20	29.0	....	....	*
	23	31.5	....	....	*
El Verde	8	12.4	16.7	....	*
	17	15.2	18.3	....	*
Guanica	21	15.2	13.7	....	*
Guanica	21	25.4	18.3	....	*
Lajas	1	4.4	3.7	....	*(61)*
	2	10.8	9.0	....	*(61)*
	5.5	11.0	16.7	....	*(61)*
Luquillo	10	20.3	17.4	....	*
	18	37.3	....	....	*
Luquillo	10	24.1	25.9	....	*
	17	36.6	....	....	*
	20	41.1	....	....	*
Maricao	20	10.2	9.1	....	*
Mona Island	12	10–25	21.5–24.6	....	*(68)*
Río Abajo	4	7.6	9.2	....	*(68)*
Río Abajo	5	6.4	5.5	....	*
Río Abajo	6	7.6	9.1	....	*
	8	8–13	12.2	....	*
	11	10.2	....	....	*
Río Abajo	7	10.4	....	12.2	*
	10	12.2	....	14.0	*
Sabana	8	12.7	12.3–16.9	16.3	*(67)*
	11	15.5	....	21.6	*
	16	17.0	....	23.0	*
St. Just	5	7.6	10.6	....	*
	10	10.4	13.7	....	*
St. Just	10	10–18	15.2	....	*
Toa Baja	1	2.9	4.1	7.9	†
	2	3.1	6.8	14.2	†

*Data on file at the International Institute of Tropical Forestry, U.S. Department of Agriculture, Río Piedras, PR 00928-2500.
†Measurements made by the author.

casuarina measured in Puerto Rico was 45.9 m tall and had a d.b.h. of 61 cm.[1]

In plantations less than 5 years old in Puerto Rico, mean annual height and d.b.h. increments range from 1.1 to 4.5 m (mean=3.3 m) and 1.3 to 5.4 cm (mean=2.7 cm), respectively. In 5.5- to 15-year-old plantations, mean annual height and d.b.h. increments range from 1.4 to 3.0 (mean=1.9 m) and 1.0 to 2.0 cm (mean=1.5 cm), respectively. In 16- to 28-year-old plantations, mean annual height and d.b.h. increments range from 0.5 to 1.1 m (mean=0.9 m) and 0.5 to 2.2 cm (mean=1.4 cm), respectively *(61, 68;* author, unpublished data).[1] Growth rates reported from Cuba *(8),* India *(85, 100),* Sri Lanka *(104),* Thailand *(114),* and the Philippines *(41)* are typically within the ranges given above, but are generally lower than the mean growth rates in Puerto Rico.

In adaptability trials conducted at 23 sites in subtropical and tropical very dry, dry, moist, and wet forest life zones (sensu Holdridge, *45)* in Guatemala, Honduras, Nicaragua, Costa Rica, and Panama, growth rates of casuarina trees varied greatly but were not clearly related to climatic factors *(13).* Most of these trials were on small-scale plantation plots that were established at densities ranging from 500 to 4,444 trees per hectare on sites located at elevations of 40 to 1,750 m. Mean annual temperatures for all sites ranged from 18.2 to 27.9 °C, annual precipitation ranged from 889 to 3140 mm, and length of the dry season ranged from 4 to 8 months. In plantations 1 to 5 years old, mean annual height and d.b.h. increments ranged from 0.4 to 2.1 m (mean=1.1 m) and 0.6 to 2.0 cm (mean=1.2 cm), respectively. In 5- to 10-year-old plantations, mean annual height and d.b.h. increments ranged from 0.9 to 1.8 m (mean=1.3 m) and 0.7 to 2.0 cm (mean=1.2 cm), respectively.

Three naturally regenerated casuarina stands surveyed on the north coast of Puerto Rico had total basal areas of 22.1, 31.7, and 39.5 m^2/ha.[1] Two of the stands, which were about 40 years old, were pure casuarina stands with densities of 4,966 and 7,003 trees per hectare, mean d.b.h.'s of 16.5 ± 1.2 and 11.7 ± 0.6 cm, and mean tree heights of 17.7 ± 1.1 and 14.9 ± 0.7 m, respectively. In the remaining stand, of unknown age, casuarina composed 92.8 percent and *Bucida buceras* L. comprised 6.4 percent of the total basal area; casuarina occurred at a density of 1,783 trees per hectare, with a mean d.b.h. and mean height of 29.8 ± 3.5 cm and 24.0 ± 3.1 m, respectively.

Average annual volume growth of casuarina trees on coastal sites in India ranged from 2.8 to 6.4 m^3/ha in 5- to 10-year-old plantations, 3.5 to 6.1 m^3/ha in 11- to 20-year-old plantations, and 5.6 to 6.3 m^3/ha in 21- to 40-year-old plantations *(92, 100).* Associated annual biomass (stemwood) yields from these plantations ranged from 2.6 to 10.3 t/ha. Elsewhere, maximum annual volume yields of 7 to 10 m^3/ha have been reported in 15- to 20-year-old plantations *(24).* Mean annual biomass yields of 9.5 and 36.2 t/ha have been reported in an 8-year-old plantation in Colombia *(52)* and a 5.5-year-old plantation in Puerto Rico, respectively *(61).* Volume tables *(11, 13, 85)* and biomass regressions *(13, 116)* have been published.

Rooting Habit.—Casuarina seedlings develop a long, thin, wiry taproot and numerous fibrous lateral roots *(100).* Mature trees typically have deep taproots and an extensive, shallow, lateral root system. Very deep taproot development and sparse lateral root development are typical of trees on sites with a deep or seasonally fluctuating water table, and poor taproot development is characteristic of trees on sites with shallow soils or a high water table *(112).* On periodically flooded sites, casuarina has been noted to root from the lower portion of the stem and from lower branches *(50).* Proteoid roots composed of tightly packed rows of rootlets have also been observed *(22; 24;* author, personal observation). The formation of these rootlet clusters, which are particularly efficient in phosphorus absorption, is believed to be induced by soil microorganisms *(65),* although recent studies have shown that their formation can be induced in axenic cultures by limiting phosphorus concentrations.[2]

Root biomass comprised 21 to 24 percent of total tree biomass in 1.5-year-old plantations in Puerto Rico (author, unpublished data). Fine roots (less than 2 mm in diameter) averaged 195 ± 21 g/m^2 in 9-month-old plantations *(81)* and 383 ± 60 g/m^2 in 2-year-old plantations in Puerto Rico (author, unpublished data). Approximately 33 and 50 percent of the total fine-root dry mass in the 9-month-old and 2-year-old stands, respectively, occurred within the upper 10 cm of the soil profile.

Fine roots readily form symbiotic associations with both ectomycorrhizal and endomycorrhizal fungi that facilitate uptake of soil nutrients, especially phosphate, and under some circumstances may facilitate water uptake and increase moisture availability *(22, 98).* A study conducted in southern Florida revealed that casuarina roots in both wet and dry sites were infected with both endotrophic and ectotrophic mycorrhizae, although ectotrophic mycorrhizae were less frequent in the wet sites *(98).* Root nodules produced by the nitrogen-fixing actinomycete *Frankia* enable casuarina trees to grow well in nitrogen-deficient soils *(32, 70). Frankia* infects the root hairs, which results in the formation of the perennial woody nodules *(1, 98).* Water stress has been found to limit both nodule formation and nitrogen fixation rates in *Frankia (48).* Double inoculation with both *Frankia* and another endophyte, *Glomus mosseae,* was found to greatly increase nodulation, nitrogen uptake and plant growth in casuarina seedlings *(33).* Estimates of annual symbiotic nitrogen fixation in casuarina stands range from 58 to 150 kg/ha *(23; 24;* author, unpublished data).

Reaction to Competition.—Casuarina is shade intolerant; in dense plantations, smaller seedlings are quickly suppressed by more vigorous individuals. Seedlings generally compete well with grasses and herbaceous weeds, except under drought conditions. In the Philippines, casuarina is recognized as one of the best species for planting on sites dominated by *Imperata cylindrica* Beauv. *(41, 72, 73).*

Plantations established primarily for fuel and pole production are typically planted at densities ranging from 1,600 to 10,000 trees per hectare and managed on rotations of 3 to 15 years, with thinnings after 4 to 5 years *(13, 50, 51, 104).* On seasonally dry sites in India, however, mortality,

[2]Baker, D.D. 1992. Personal communication with author. On file at: Yale University, School of Forestry and Environmental Studies, New Haven, CT.

poor growth, and increased susceptibility to pests and diseases are common in plantations established at densities greater than 2,500 trees per hectare *(50, 100)*.

A spacing study conducted at a coastal site in Orissa, India, compared growth and yield in plantations established at tree spacings of 1.83 by 1.83, 2.74 by 2.74, and 3.66 by 3.66 m *(91, 92)*. The results showed that maximum mean annual volume increments were attained within the first 7 years with the two closest spacing treatments. Total volume production was significantly greater at these spacings for up to 19 years, and thinning after 7 years did not influence subsequent growth. These results suggest that plantations managed for both small- and large-diameter poles can be established at close spacings (1.83 by 1.83 m), thinned at 7 years of age, and harvested at 15 years of age for optimal production. In 2-year-old plantations in Thailand, the mean stem diameter (d.b.h.) decreased from 5.5 to 3.1 cm as stand densities increased from 3,333 to 20,000 trees per hectare *(115)*.

Casuarina is sometimes cultivated in mixed-species plantations and in agroforestry systems *(55)*. In India, first-year plantations are commonly underplanted with peanuts, sesame, pulses, cucumbers, or melons, depending on the prevailing climatic conditions and types of soils at each site. Tree species sometimes interplanted with casuarina in India include *Anacardium occidentale* L., *Azadirachta indica, Cocos nucifera* L., *Dalbergia sissoo* Roxb., *Pithecellobium dulce* (Roxb.) Benth., *Pongamia glabra, Sapindus laurifolius* Vahl, and *Syzygium jambos* (L.) Alst. *(100)*. Mixed plantations established at a strip-mined limestone quarry in Kenya with casuarina, *Conocarpus lancifolius,* and *A. indica* have produced good yields *(76)*. In Puerto Rico, plantations have been established with casuarina, *Leucaena leucocephala,* and *Eucalyptus robusta* Sm. (author, unpublished data). After 2 years, growth of casuarina and the associated species in the mixed stands was significantly greater than growth of trees in monocultural plantations.

Damaging Agents.—In the nursery, seed predation by ants is a major problem that can be controlled by application of carbolic acid solution or other appropriate formicidal agents to germination beds. Seedlings are also susceptible to damping-off disease caused by soil fungi of *Rhizoctonia* spp. *(41, 49)* and to browsing by rodents, crabs, crickets, and grasshoppers *(50, 76, 100)*. Because casuarina foliage is less palatable than that of most trees, it is not usually browsed by livestock *(50)*.

In Puerto Rico, casuarina is the host of numerous species of insects of the orders Coleoptera, Homoptera, Isoptera, Lepidoptera, and Orthoptera *(69)*, although few of these insects, if any, cause serious damage in plantations or naturalized stands. Several insect pests known to cause damage in casuarina plantations in Cuba include the stem and twig borer *Apate monachus* (F.), the leaf cutting ant *Atta insularis* (Guér.), the Australian pine spittlebug *Clastoptera undulata* Uhler., *Crypticerya rosae* (R. & H.), *Eocader bouclei* (Brun.), the cottony cushion scale *Icerya purchasi* Mask., and the wood borer *Neoclytus cordifer* Klug. *(8)*. In southern Florida, the twig girdler *Oncideres cingulata,* the thorn bug *Umbonia crassicornis,* the Australian pine spittlebug *C. undultata,* and the leaf notcher weevil *Artipus floridanus* are reported to cause minor damage to casuarina *(16)*. Bark and wood boring insects known to cause serious damage to casuarina include *Arbela tetraonis, Coelosterna scabrata,* and *Phassus malabaricus* in India *(50, 100)* and *Macrotoma palmata* F. in Egypt *(43)*. Termite infestations have been reported in coastal plantations in Senegal *(90)*. Defoliation by larvae of the coleopteran *Lixus camerunus* Kolbe has been reported in Nigeria *(28)*. Severe defoliation by the cotton locust *Chondracis rosea rosea* has been reported in southern China *(95)*. Attack by the root knot nematode *(Meloidogynes* sp.) has been reported in Florida *(103)*.

Casuarina is susceptible to a number of fungal pathogens within its native and introduced ranges. Mature trees are susceptible to root rot caused by *Armillaria mellea* Vahl ex Fr. in California and *Clitocybe tabescens* (Scop. ex Fr.) Bres. in Florida *(103)*. Heart rot caused by *Fomes applanatus* (Pers. ex Wallr.) Gill. and *Phellinus kawakamii* has been reported in Hawaii *(53, 103)*. In the Caribbean region, *Diplodia natalensis* Pole Evans had been reported to cause stem-end rot, dieback, twig blight, trunk rot, and stem canker in Puerto Rico *(59)*. An unidentified virus causing mottling and stunting of foliage, brooming, and multiple budding has been reported in Mexico and Central America *(97)*. Elsewhere in the world, major pathogens of casuarina include the fungi *Ganoderma lucidum* (in Taiwan), *Sclerotium rolfsii,* and *Phytophthora cambivora* that cause root rot and the bacterium *Pseudomonas solanacearum* that causes wilt *(44, 56, 120)*.

In India, large-scale mortality in casuarina plantations has been attributed to attack by the fungal pathogens *Trichosporium vesiculosum,* a wound parasite, and *Ganoderma lucidum (3, 6, 50)*. *Phomopsis causuarinae,* a fungus that is normally symbiotic with casuarina, may become parasitic under certain conditions and has been identified as a cause of tree death in southern India *(112)*.

Casuarina is highly resistant to wind damage *(7, 101)*. Although young trees can withstand hurricane-force winds with little or no damage *(80)*, serious damage has occurred in older plantations in Puerto Rico.[1] Casuarina is highly susceptible to fire damage *(76, 100)*. In some regions, such as India and China, litter is routinely removed from plantations for use as fuel and to reduce the risk of fire *(100, 101)*.

SPECIAL USES

Casuarina wood is very hard and heavy (specific gravity of 0.80 to 1.20 g/cm^3 for air-dried wood and 0.61 g/cm^3 for wood with a moisture content of 46 percent *[117])* and is exceptionally strong and tough *(25, 60)*. The heartwood is a dull reddish brown, occasionally with dark-brown streaks, and is not easily separated from the pinkish sapwood. The wood has a very fine texture, medium luster, and tightly interlocked grain. The wood dries at a moderate rate and degrades considerably during the process. Seasoning is accompanied by heavy and relatively uneven shrinkage. Casuarina logs are very difficult to saw in small circular sawmills, and because of its density and hardness, air-dried casuarina lumber is also difficult to machine, although machined surfaces are usually of good quality *(60)*. Casuarina is rated as a good wood for boring and mortising, and it sands to a very smooth finish. For a wood of such high density, casuarina's tightly interlocked grain gives it good resis-

tance to splitting by screws *(60)*. The wood is very susceptible to attack by the dry-wood termite *Cryptotermes brevis* (Walker) and has only limited durability unless treated with preservatives *(25, 60, 108)*. Untreated fenceposts have a useful life of 2 years, and larger poles remain durable for up to 5 years without treatment.[1]

The wood and cones of casuarina make excellent fuels (particularly charcoal), produce little ash, and burn satisfactorily even when green *(57)*. Air-dried wood has a calorific value of 4.1 to 4.9 kcal/g *(89, 107)*. Although casuarina wood is difficult to use for fine carpentry, it is widely used for making utility poles and house posts, rafters, beams, wagon wheels, tool handles, shingles, and small items such as oars *(25)*. It is a suitable raw material for chemical and semichemical pulps and for paper production *(37, 38, 63, 118)*.

Casuarina is widely planted for windbreaks and erosion control, such as along sandy coasts, sand dunes, and riverbanks *(10, 15, 27, 47, 64, 86)*. It is also grown as an ornamental and as a street (shade) tree, especially along coasts, and is sometimes pruned into hedges *(57)*. Casuarina trees have been cultivated in India since the 1860's in large plantations for fuelwood and posts. Approximately 1 million ha of casuarina plantations have been established in China since 1954 in about 3,000 km of shelterbelt plantings ranging form 0.5 to 5 km in width *(101)*. It is a valuable species for rehabilitation of degraded or naturally infertile soils due to its nitrogen-fixing capabilities and high rates of litter production *(36)*, which facilitate the early successional development of microflora, microfauna, and insect communities and increase nutrient availability. In India, where casuarina trees are used for this purpose, the combined accumulation of forest floor biomass and soil organic matter beneath a 12-year-old plantation established on coastal sands was estimated to be 70.8 t/ha, with litter and humus additions comprising 39 percent of the total *(50)*. In Puerto Rico, total stocks of standing litter amounted to 16.2 t/ha in 5.5-year-old plantation stands *(61)*. When compared with other plantation species *(Leucaena leucocephala, Albizia procera,* and *Eucalyptus robusta),* casuarina was found to have the highest nutrient-use efficiency, producing the greatest quantity of total aboveground biomass per unit of nitrogen, phosphorus, potassium, and magnesium utilized *(105)*.

The bark of casuarina trees is rich in tannin (6 to 8 percent) and is used in some locales for dyeing fishing nets and leather *(12, 13, 21)*. The bark and branchlets are claimed to have medicinal properties and are used by native New Zealanders in the treatment of beriberi *(13)*. Chemical analysis of the fruits yielded ellagic acid, beta-sitosterol, and kaempferol-3-beta-D-galactoside *(78)*. Casuarina has limited value as a source of fodder, but is sometimes used for this purpose during periods of severe drought *(25)*.

GENETICS

Casuarina exhibits a high degree of phenotypic variation with regard to shape of crown, angle of branches, length of branchlets, size and shape of cones, production of cones *(82)*, and propensity to produce roots from the lower stem under flooded conditions *(50)*. Significant differences in seedling growth among Philippine provenances *(41)* and variations in growth rate *(46, 79, 94, 121)* and nitrogen-fixing potential of individual genotypes *(94)* have been reported. Hybridization is known to occur between *C. equisetifolia* and other *Casuarina* species, especially *C. glauca* Sieb. ex. Spreng. *(24, 106, 110)* and *C. junghuhniana* Miq. *(24)*.

The genus *Casuarina* consists of about 52 species and includes species ranging in size from bushes less than 1 m in height to forest trees 20 to 30 m in height *(25)*. Members of the genus that have been studied extensively are *C. cunninghamiana* Miq., *C. glauca, C. junghuhniana,* and *C. oligodon* L. Johnson. Other species with demonstrated or potential value for plantations include *C. campestris* Miq., *C. cristata* Miq., *C. decaisneana* F. Muell., *C. dielsiana* C. A. Gardn., *C. fraseriana* Miq., *C. huegeliana* Miq., *C. littoralis* Salisb., *C. leuhmanii* (R.T. Baker), *C. obesa* Miq., *C. stricta* Ait., and *C. torulosa* Ait. *(76)*. In Puerto Rico, limited trials have been conducted with *C. cunninghamiana, C. glauca,* and *C. cristata.*[1]

The generic name alludes to the drooping filamentous branchlets that resemble the plumage of the cassowary bird *(Casuarius* spp.); the specific epithet *equisetifolia,* meaning "horsetail," refers to the herbaceous genus *Equisetum,* which has similar foliage *(57, 76)*. The species was formerly known as *C. litorea* L.

LITERATURE CITED

1. Abdel Wahab, A.M. 1980. Nitrogen-fixing nonlegumes in Egypt. 1: Nodulation and $N_2(C_2H_2)$ fixation by *Casuarina equisetifolia.* Zeitschrift für Allgemeine Mikrobiologie. 20(1): 3–12.
2. Andéké-Lengui, M.A.; Dommergues, Y. 1983. Coastal dune stabilization in Senegal. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 158–166.
3. Bagchee, K. 1952. A review of work on Indian tree diseases and decay of timber and methods of control. Indian Forester. 78(11): 540–546.
4. Bandyopadhyay, A.K. 1986. *Casuarina equisetifolia* grows well in heavy-textured coastal saline soils. Indian Farming. 36(5): 19.
5. Barlow, B.A. 1983. The casuarinas—a taxonomic and biogeographic review. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 10–18.
6. Begum, R.; Rizwana, A.R. 1979. Blister disease—threat to *Casuarina.* Geobios. 6(1): 35–36.
7. Bell, T.I.W.; Evo, T.; Sakumeni, A. 1983. Cyclones and stability in Fiji's pine forests. Fiji Pine Res. Pap. 14. Suva, Fiji: Fiji Pine Commission/Fiji Forestry Department. 12 p.
8. Betancourt-Barroso, A. 1987. Silvicultura especial de árboles maderables tropicales. Havana: Editorial Científico-Técnica. 427 p.

9. Bhaskar, V.; Dasappa. 1986. Ground flora in *Eucalyptus* plantations of different ages. In: Sharma, J.K.; Nair, C.T.S.; Kedharnath, S.; Kondas, S., eds. Eucalypts in India: past, present and future: Proceedings of a seminar; 1984 January 30–31; Peechi, India. Peechi, India: Kerala Forest Research Institute: 213–224.
10. Bilaidi, A.S. 1978. Silviculture in the People's Democratic Republic of Yemen. Unasylva. 30(121): 29–32.
11. Bredenkamp, B.V. 1981. A preliminary volume table for *Casuarina equisetifolia* [in South Africa]. South African Forestry Journal. 118: 90.
12. Browne, F.G. 1955. Forest trees of Sarawak and Brunei and their products. Kuching, Sarawak, Malaysia: Government Printing Office. 369 p.
13. Centro Agronómico Tropical de Investigacíon y Enseñanza (CATIE). 1991. *Casuarina equisetifolia* L. ex J.R. Forst. & G. Forst., árbol de uso múltiple en America Central. Rep. No. 173, Tech. Series. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigacíon y Enseñanza. 51 p.
14. Champion, H.G. 1936. A preliminary survey of the forest types of India and Burma. Indian Forest Records I(1). New Delhi: Government of India Press. 286 p.
15. Chang, S.K.; Hu, C.; Song, S. [and others]. 1976. Improvement of second rice crop in southern and central Taiwan. I: Studies on the methods of raising rice yields in ill-drained and west coast areas of Changhua Hsien. Taiwan Agriculture Quarterly. 12(3): 90–97.
16. Chellman, Charles W. 1978. Pests and problems of south Florida trees and palms. Tallahassee, FL: Florida Department of Agriculture and Consumer Services, Division of Forestry. 103 p.
17. Clemens, J.; Campbell, L.C.; Nurisjah, S. 1983. Germination, growth and mineral ion concentrations of *Casuarina* species under saline conditions. Australian Journal of Botany. 31: 1–9.
18. Craig, R.M.; Smith, D.C.; Ohlsen, A.C. 1978. Changes occurring in coastal dune formation and plant succession along the Martin County coastline. Proceedings, Soil and Crop Science Society of Florida. 37: 14–17.
19. Craighead, Frank C., Sr. 1971. The trees of south Florida. The natural environments and their succession. Coral Gables, FL: University of Miami Press. 212 p. Vol. 1.
20. Crowder, J.P. 1974. Exotic pest plants of south Florida. South Florida Environmental Project, Ecological Rep. DI-SFEP-74-23. Atlanta, GA: U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife. 49 p.
21. Dastur, J.F. 1964. Useful plants of India and Pakistan. Bombay: D.P. Taraporevala Sons & Co. 185 p.
22. Diem, H.G.; Gueye, I.; Gianinazzi-Pearson, V. [and others]. 1981. Ecology of VA mycorrhizae in the Tropics: the semi-arid zone of Senegal. Acta Oecologica, Oecologia Plantarum. 2(1): 53–62.
23. Dommergues, Y. 1963. Evaluation du faux de fixation de l'azote dans un sol dunaire reboise en Filao. Agrochimica (Pisa). 7(4): 335–340.
24. Dommergues, Y. 1990. *Casuarina equisetifolia:* an old-timer with a new future. NFT Highlights 90-02. Waimanalo, HI: Nitrogen Fixing Tree Association. 2 p.
25. Doran, J.; Hall, N. 1983. Notes on fifteen Australian casuarina species. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 19–52.
26. Duhoux, E.; Leroux, C.; Phelep, M.; Sougoufara, B. 1990. Improving Casuarinaceae using *in vitro* methods. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 174–187.
27. El-Lakany, M.H. 1983. Breeding and improving of casuarina: a promising multipurpose tree for arid regions of Egypt. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 58–65.
28. Eluwa, M.C. 1979. Biology of *Lixus camerunus* Kolbe (Coleoptera Curculionidae): a major pest of the edible vernonias (Compositae) in Nigeria. Revue de Zoologie Africaine. 93(1): 223–240.
29. Esbenshade, H.W.; Grainger, A. 1980. The Bamburi reclamation project. International Tree Crops Journal. 1(2/3): 199–202.
30. Ewel, John J.; Whitmore, Jacob L. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. Res. Pap. SO-ITF-18. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Río Piedras, PR 00928-2500. In cooperation with: Institute of Tropical Forestry, University of Puerto Rico, Río Piedras, PR 00928-2500. 72 p.
31. Francis, John K.; Liogier, Henri A. 1991. Naturalized exotic tree species in Puerto Rico. Gen. Tech. Rep. SO-82. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 12 p.
32. Gauthier, D.; Diem, H.G.; Dommergues, Y. 1981. *In vitro* nitrogen fixation by two actinomycete strains isolated from *Casuarina* nodules. Applied and Environmental Microbiology. 41(1): 306–308.
33. Gauthier, D.; Diem, H.G.; Dommergues, Y. 1983. Preliminary results of research on *Frankia* and endomycorrhizae associated with *Casuarina equisetifolia.* In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 211–217.
34. Geary, T.F. 1983. Casuarinas in Florida, USA and some Caribbean islands. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 107–109.

35. Geary, Thomas F.; Briscoe, C. Buford. 1972. Tree species for plantations in the granitic uplands of Puerto Rico. Res. Pap. SO-ITF-14. New Orleans: LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Río Piedras, PR 00928-2500. In cooperation with: Institute of Tropical Forestry, University of Puerto Rico, Río Piedras, PR 00928-2500. 8 p.
36. Geigel, F.B. 1977. Materia orgánica y nutrientes devueltos al suelo mediante la hojarasca de diversas especies forestales. Baracoa. 7(3/4): 15–38.
37. Guha, S.R.D.; Karira, B.G. 1981. Chemical, semi-chemical and chemi-mechanical pulps from *Casuarina equisetifolia*. Indian Forester. 107(3): 174–177.
38. Guha, S.R.D.; Sharma, Y.K.; Pant, R.; Shoundiyal, S.N. 1970. Chemical, semi-chemical and mechanical pulps from *Casuarina equisetifolia*. Indian Forester. 96(11): 830–840.
39. Gupta, B.N.; Pattanath, P.G.; Kumar, Adarsh [and others]. 1975. Rules for germination test of tree seeds for certification. Indian Forester. 101: 320–327.
40. Hallé, F. 1978. Arbres et forêts des Îles Marquises. Cahiers du Pacifique. 21: 315–357.
41. Halos, Saturnina C. 1983. Casuarinas in Philippine forest development. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 89–98.
42. Halos, Saturnina C. 1983. Production practices for *Casuarina equisetifolia*. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 133–134.
43. Hassan, Fatma A. 1990. Important insect pests of casuarina in Egypt. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 102–109.
44. Hepting, George H. 1971. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture. 658 p.
45. Holdridge, L.R. 1967. Life zone ecology. San José, Costa Rica: Tropical Science Center. 206 p.
46. Jambulingam, R. 1990. Recent developments in research on *Casuarina* in Tamil Nadu. I: Variation in populations. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 45–54.
47. Jumale, M.M. 1980. Sand-dune control in the Marka area of Somalia. Somali Range Bulletin. 10: 18–20.
48. Kant, S.; Narayana, H.S. 1978. Effect of water stress on growth, nodulation and nitrogen fixation in *Casuarina equisetifolia*. Annals of Arid Zone. 17(2): 216–221.
49. Ko, W.H.; Hunter, J.E.; Kunimoto, R.K. 1973. *Rhizoctonia* disease of Queensland maple seedlings. Plant Disease Reporter. 57(11): 907–909.
50. Kondas, S. 1983. *Casuarina equisetifolia*—a multipurpose tree cash crop in India: In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 66–76.
51. Kondas, S.; Jambulingam, R.; Dasthagir, M.G.; Vinaya Rai, R.S. 1985. Studies on *Casuarina equisetifolia* (L.) Forst. Indian Journal of Forestry. 8(4): 262–264.
52. Ladrach, W.E. 1987. Growth of the Guachicona arboretum—eight year results of the 1977 planting—three year results of the 1977, 1980 and 1981 planting. Res. Rep. 112. Cali, Colombia: Cartón de Colombia. 16 p.
53. Larsen, M.J.; Lombard, F.F.; Hodges, C.S., Jr. 1985. Hawaiian forest fungi. 5: A new species of *Phellinus* (Hymenochaetaceae) causing decay of *Casuarina* and *Acacia*. Mycologia. 77(3): 345–352.
54. Le Roux, P.J. 1974. Establishing vegetation in saline soil to stabilise aeolian sand at Walvis Bay, South-West Africa. Forestry in South Africa. 15: 43–46.
55. Li, C.F. 1984. Experiment on establishing a plantation of *Cinnamonmum camphora* mixed with other species. Forest Science and Technology (Linye Keji Tongxun). 1: 6–9.
56. Liang, Z.C.; Chen, X.H. 1984. Selection of clones of casuarina for resistance to bacterial wilt. Journal of South China Agricultural College. 5(1): 53–59.
57. Little, Elbert L., Jr. [n.d.]. Common fuelwood crops: a handbook for their identification. Morgantown, WV: Communi-Tech Associates. 354 p.
58. Little, Elbert L., Jr.; Wadsworth, Frank H. 1964. Common trees of Puerto Rico and the Virgin Islands. Agric. Handb. 249. Washington, DC: U.S. Department of Agriculture. 548 p.
59. Liu, L.-J.; Martorell, L.F. 1973. *Diplodia* stem canker and die-back of *Casuarina equisetifolia* in Puerto Rico. Journal of Agriculture of the University of Puerto Rico. 42(3): 255–261.
60. Longwood, Franklin R. 1961. Puerto Rican woods. Agric. Handb. 205. Washington, DC: U.S. Department of Agriculture. 98 p.
61. Lugo, Ariel E.; Wang, Deane; Bormann, F. Herbert. 1990. A comparative analysis of biomass production in five tropical tree species. Forest Ecology and Management. 31: 153–166.
62. Lundquist, Ralph; Torrey, John G. 1984. The propagation of casuarina species from rooted stem cuttings. Botanical Gazette. 145(3): 378–384.
63. Maheswari, S.; Nayak, R.G.; Meshramkar, P.M.; Jaspal, N.S. 1979. Comparative studies on the pulping and papermaking properties of *Casuarina equisetifolia* and *Eucalyptus* hybrid. Indian Pulp and Paper. 34(3): 9–13.
64. Maheut, J.; Dommergues, Y. 1959. Fixation par le reboisement des dunes de la presqu'île du Cap-Vert et l'evolution biologique des sols. Bois et Forêts des Tropiques. 63: 3–16.

65. Malajczuk, N.; Bowen, G. 1974. Proteoid roots are microbial induced. Nature (London). 251: 316–317.
66. Malik, M.N.; Sheikh, M.I. 1983. Planting of trees in saline and waterlogged areas. Part 1: Test planting at Azakhel. Pakistan Journal of Forestry. 33(1): 1–17.
67. Marrero, José. 1948. Forest planting in the Caribbean National Forest—past experience as a guide for the future. Caribbean Forester. 9(2): 85–148.
68. Marrero, José. 1950. Results of forest planting in the insular forests of Puerto Rico. Caribbean Forester. 11(3): 107–147.
69. Martorell, Luís F. 1975. Annotated food plant catalog of the insects of Puerto Rico. Río Piedras, PR: University of Puerto Rico, Agricultural Experiment Station, Department of Entomology. 303 p.
70. McCluskey, D.N.; Fisher, R.F. 1983. The effect of inoculum source on nodulation in *Casuarina glauca.* Commonwealth Forestry Review. 62(2): 117–124.
71. Mekhtiev, T.A.; Mamedov, F.M. 1974. The overwintering of some subtropical plants on the Apsheron peninsula [in the Caspian Sea] in harsh winters. Byulleten' Glavnogo Botanicheskogo Sada. 91: 21–23.
72. Mendoza, V.B. 1978. Adaptability of six tree species to cogonal areas: additional information on the possible role of phenols and sugars. Sylvatrop. 3(1): 1–7.
73. Mendoza, V.B.; de la Cruz, R.E. 1978. Adaptability of six tree species to cogonal areas. 3: Field experiment and additional information. Sylvatrop. 3(2): 93–106.
74. Midgley, S.J.; Turnbull, J.W.; Hartney, V.J. 1986. Fuel-wood species for salt affected sites. Reclamation and Revegetation Research. 5(1/3): 285–303.
75. Morton, J.F. 1976. Pestiferous spread of many ornamental and fruit species in South Florida. Proceedngs, Florida State Horticultural Society. 89: 348–353.
76. National Research Council. 1984. Casuarinas: nitrogen fixing trees for adverse sites. Washington, DC: National Academy Press. 118 p.
77. Nayar, R.; Ramanujam, B. 1986. Mortality in *Casuarina* plantations in Karnataka. Myforest. 22(4): 211–216.
78. Neelakantan, S. 1986. Constituents of the fruits of *Casuarina equisetifolia.* Fitoterapia. 57(2): 120–121.
79. Pan, Zhigang; Lu, Pengxin. 1990. Preliminary reports on *Casuarina* species and provenance tests in Donghai forest farm. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 40–44.
80. Parrotta, J.A. 1990. Hurricane damage and recovery of seedlings of multi-purpose tree species at a coastal site in Puerto Rico. Nitrogen Fixing Tree Research Reports. 8: 64–66.
81. Parrotta, J.A. 1991. Effect of an organic biostimulant on early growth of *Casuarina equisetifolia, Eucalyptus tereticornis, Leucaena leucocephala,* and *Sesbania sesban* in Puerto Rico. Nitrogen Fixing Tree Research Reports. 9: 50–52.
82. Rai, R.S. Vinaya. 1990. Seed management in *Casuarina equisetifolia.* In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 78–84.
83. Rai, R.S. Vinaya; Natarajan, N. 1988. Studies on nursery technology and planting density in *Casuarina equisetifolia.* Indian Journal of Forestry. 11(1): 60–62.
84. Rai, S.N.; Shettigar, D. 1979. Afforestation of grassy blanks in high rainfall zone of Karnataka. Res. Pap. No. KFD-1. Bangalore, India: Karnataka Forest Department. 13 p.
85. Ray, M.P. 1971. Plantations of *Casuarina equisetifolia* in the Midnapore District, West Bengal. Indian Forester. 97(8): 443–457.
86. Reddy, C.V.K. 1979. Shelter belts against storms and cyclones on the coast. Indian Forester. 105(10): 720–726.
87. Rivero, M.; Vargas, Y.M. 1990. Influencia de la densidad de siembra en la producción de posturas de *Casuarina equisetifolia* a raíz desnuda en vivero. Revista Forestal Baracoa. 20(1): 35–45.
88. Rockwood, D.L.; Fisher, R.F.; Conde, L.F.; Huffman, J.B. 1990. *Casuarina* L. ex Adans. In: Burns, Russell M.; Honkala, Barbara H., tech. coordinators. Silvics of North America. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 240–243. Vol. 2.
89. Rodriguez Perez, M. 1973. Determining the calorific value of *Eucalyptus saligna, Casuarina equisetifolia, Jambos vulgaris [Eugenia jambos]* and *Buchenavia capitata.* Baracoa. 3(1/2): 45–49.
90. Roy-Noel, J.; Wane, C. 1977. L'attaque des arbres par les termites dans la preqsu'île du Cap-Vert (Senegal). 1: Cas du roboisement sur dunes vives de Malika. Bulletin de l'Institute Fondamental d'Afrique Noire. 39(1): 124–141.
91. Singh, S.P. 1978. Rotation as influenced by stand stocking: a study of *Casuarina equisetifolia.* Indian Forester. 104(7): 491–500.
92. Singh, S.P.; Sharma, R.S.; Jain, R.C. 1983. Effects of spacing and thinning in *Casuarina* stands. Indian Forester. 109(1): 12–16.
93. Somasundaram, T.R.; Jagadees, S.S. 1977. Propagation of *Casuarina equisetifolia* Forst. by planting shoots. Indian Forester. 103(11): 735–738.
94. Sougoufara, B.; Duhoux, E.; Corbasson, M.; Dommergues, Y. 1986. Improvement of nitrogen fixation by *Casuarina equisetifolia* through clonal selection. Presented paper: 18th IUFRO World Congress: 1986 September 7–21; Ljubljana, Yugoslavia: International Union of Forest Research Organizations. 5 p.
95. Su, X.; Yu, X.D. 1979. A preliminary study of cotton locust—an insect pest of beef wood on Dong-Hai Island, Kwantung [Guangdong] Province. Scientia Silvae Sinicae. 15(3): 171–177.
96. Thaiutsa, Bunvong. 1990. Estimating productivity of *Casuarina equisetifolia* grown on tin-mine lands. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 94–101.

97. Titze, J.F.; van der Pennen, Elizabeth. 1983. Provisory list of diseases of *Casuarina* species. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 220–222.
98. Torrey, J.G. 1983. Casuarina: actinorhizal dinitrogen-fixing tree of the tropics. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 193–204.
99. Torrey, J.G. 1983. Root development and root nodulation in *Casuarina*. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 180–192.
100. Troup, R.S. 1921. The silviculture of Indian trees. Oxford, UK: Clarendon Press. 1195 p. 3 vol.
101. Turnbull, J.W. 1983. The use of *Casuarina equisetifolia* for protection forests in China. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 55–57.
102. Turnbull, J.W.; Martensz, P.N. 1983. Seed production, collection and germination in Casuarinaceae. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 126–132.
103. U.S. Department of Agriculture. 1960. Index of plant diseases in the United States. Agric. Handb. 165. Washington, DC: U.S. Department of Agriculture. 531 p.
104. Vivekanandan, K. 1983. The status of casuarina in Sri Lanka. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 99–101.
105. Wang, Deane; Bormann, F. Herbert; Lugo, Ariel E.; Bowden, Richard D. 1991. Comparison of nutrient-use efficiency and biomass production in five tropical tree taxa. Forest Ecology and Management. 46: 1–21.
106. Wang, T.T.; Yang, J.C.; Chen, Z.Z. 1984. Identification of hybridity of casuarinas grown in Taiwan. Silvae Genetica. 33(4/5): 128–133.
107. Webb, Derek B.; Wood, Peter J.; Smith, Julie P.; Henman, G. Sian. 1984. A guide to species selection for tropical and sub-tropical plantations. 2d ed. Trop. For. Pap. 15. Oxford, UK: University of Oxford, Commonwealth Forestry Institute, Unit of Tropical Silviculture. 256 p.
108. Wolcott, G.N. 1946. A list of woods arranged according to their resistance to the attack of the West Indian dry-wood termite, *Cryptotermes brevis* (Walker). Caribbean Forester. 7(4): 329–334.
109. Wong, P.P. 1978. The herbaceous formation and its geomorphic role, east coast, Peninsula Malaysia. Malayan Nature Journal. 32(2): 129–141.
110. Woodall, Steven L.; Geary, Thomas F. 1985. Identity of Florida casuarinas. Res. Note SE-332. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 10 p.
111. Xu, Y.Q.; Long, W.B. 1983. The adaptive character and species choice of main planting trees of farmland shelterbelt in the Pearl River delta. Scientia Silvae Sinicae. 19(3): 225–234.
112. Yadav, J.S.P. 1983. Soil limitations for successful establishment and growth of casuarina plantation. In: Midgley, S.J.; Turnbull, R.D.; Johnston, R.D., eds. Casuarina ecology, management and utilization: Proceedings of a workshop; 1981 August 17–21; Canberra, Australia. Melbourne: Commonwealth Scientific and Industrial Research Organization: 138–157.
113. Yadav, J.S.P.; Banerjee, S.P.; Bandola, K.C. 1977. Soil characteristics of coastal alluvium supporting *Casuarina equisetifolia* in Maharashtra and Gujarat. Fertilizer Technology (India). 14(3): 208–213.
114. Yantasath, K.; Supatanakul, W.; Ungvichian, I. [and others]. 1985. I: Species trials of NFT. Nitrogen Fixing Tree Research Reports. 3: 48–49.
115. Yantasath, K.; Supatanakul, W.; Ungvichian, I. [and others]. 1985. II: Spacing trials of NFT. Nitrogen Fixing Tree Research Reports. 3: 49–50.
116. Yantasath, K.; Supatanakul, W.; Ungvichian, I. [and others]. 1985. III: Determination of biomass production of NFT using allometric regression equation. Nitrogen Fixing Tree Research Reports. 3: 51–53.
117. Yantasath, K.; Supatanakul, W.; Ungvichian, I. [and others]. 1985. IV: Tissue analysis and heating parameters of NFT. Nitrogen Fixing Tree Research Reports. 3: 53–54.
118. Yantasath, K.; Supatanakul, W.; Ungvichian, I. [and others]. 1985. V: Pulping and papermaking characteristics of fast growing trees. Nitrogen Fixing Tree Research Reports. 3: 54–56.
119. Ye, M.F. 1984. Effects of plant growth regulators on rooting of cuttings of several tree species. Plant Physiology Communications. 4: 28–29.
120. Ying, S.L.; Chien, C.Y.; Davidson, R.W. 1976. Root rot of *Acacia confusa*. Quarterly Journal of Chinese Forestry. 9(1): 17–21.
121. Zhong, Chonglu. 1990. Casuarina species and provenance trial on Hainan Island, China. In: El-Lakany, M.H.; Turnbull, J.W.; Brewbaker, J.L., eds. Advances in casuarina research and development: Proceedings of a workshop; 1990 January 15–20; Cairo, Egypt. Cairo: Desert Development Center, American University in Cairo: 32–39.